

Increased Risk of Stroke Associated Pneumonia After Intracerebral Hemorrhage: Evidence from Single Center Cohort and A Meta-Analysis

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Abstract

Background:

Stroke-associated pneumonia (SAP) is a common complication after intracerebral hemorrhage (ICH), contributing to increased mortality and prolonged hospitalization. Reported incidence of SAP varies, ranging from 7% to 38%¹, with Chinese guidelines citing a rate of 16.9%^{1,2}. As these estimates were derived from earlier cohorts reported in or before 2019, we reassessed the risk of SAP after ICH to investigate whether the SAP burden showed an increasing trend after 2019

Methods:

We reassessed the risk of SAP after ICH. We conducted a retrospective analysis of patients with ICH admitted to West China Hospital between 2021 and 2024 to determine the in-hospital cumulative risk of SAP or within 7 days. In addition, we performed a meta-analysis of 18 studies reporting SAP in ICH. We conducted subgroup analyses, sensitivity analyses, meta-regression, and tests for publication bias.

Results

In the West China Hospital cohort (2021–2024), 48% (936/1,931) of patients with ICH developed SAP within 7 days or before discharge. In the meta-analysis of 18 studies, the pooled proportion of SAP was 22% (95% CI, 19%–25%) before 2019, 39% (95% CI, 24–57%) after 2019 and 48% (95%CI, 35%-62%) spanning periods before and after 2019. Sensitivity analyses and meta-regression suggested a possible temporal increase trend in the risk of SAP after ICH, while publication bias was not consistently observed.

Conclusion

The risk of SAP after ICH may be higher than previously reported. The meta-analysis suggested a possible upward trend in the risk of SAP over time, suggesting that earlier studies may have underestimated the burden.

Introduction

ICH is a severe neurological condition and remains a major cause of death and disability worldwide³. Despite advances in acute stroke care, the mortality and disability rate of ICH can reach up to 50%, highlighting the substantial clinical and societal burden of this disease⁴. ICH is a heterogeneous condition, with hematoma location contributing to differences in etiology, clinical presentation, and early prognosis. Previous evidence suggests that acute lobar ICH presents a different clinical profile and a more severe early prognosis than deep subcortical ICH⁵, and is more frequently associated with non-hypertensive mechanisms. These location-related differences may partly influence the risk and interpretation of ICH related complications. Among the complications that occur after ICH, pneumonia is

particularly common and clinically significant⁶. Post-stroke pneumonia leads to prolonged hospitalization, worsens functional outcomes, increases the risk of poor prognosis, and contributes directly to mortality.⁷ SAP has been defined as a lower respiratory tract infection occurring within 7 days of stroke onset⁸, encompassing both ischemic and hemorrhagic stroke. The diagnosis of SAP is generally based on the modified Centers for Disease Control and Prevention (CDC) criteria, incorporating clinical symptoms, laboratory findings, and imaging evidence⁹.

The reported incidence of SAP varies widely across studies, ranging from 7% to 38%¹⁰. According to the 2019 Chinese guidelines for SAP management, the incidence among patients with ICH was reported to be 16.8%¹.

However, these figures were largely derived from studies published more than a decade ago^{1,2}, in which patient enrollment ended before 2015. It is therefore uncertain whether historical estimates remain representative of the current situation. Misestimation of the risk of SAP after ICH may lead to inappropriate allocation of resources. Updated data are essential to understand the contemporary burden of SAP and ICH, inform clinical decision-making, and optimize preventive and therapeutic interventions. An underestimated incidence may lead to insufficient recognition of disease burden, optimal allocation of healthcare resources, and limitations in clinical decision-making¹¹. In addition, because SAP following ICH often necessitates empirical antibiotic administration and chest CT imaging, underestimation of its incidence may consequently lead to nondepreciating of the related healthcare expenditures¹².

In this study, we aimed to investigate the recent risk of SAP in ICH patients. We analyzed data from patients admitted to West China Hospital between 2021 and 2024 and conducted a meta-analysis including prediction models for ICH-associated SAP to estimate the in-hospital cumulative risk. Our goal was to provide updated estimates of the risk of SAP after ICH and to determine whether the risk may have increased compared with historical reports.

Methods

West China Hospital Cohort

Study Population

We established a retrospective cohort of patients diagnosed with primary ICH who were admitted to West China Hospital, Sichuan University. This cohort included individuals whose first hospitalization for the current ICH episode occurred at the center. The cohort participants were recruited consecutively from January 2021 to December 2024.

In total, the electronic health records (EHR) of primary ICH patients were screened for eligibility. Patients were included if they were ≥ 18 years old at the time of admission and had available lung CT imaging for the assessment of pneumonia. After further excluding participants with incomplete medical records or de-identified data that prevented accurate characterization, the 1,931 remaining participants were included in the primary analysis (Figure 1). These participants were followed through their acute hospitalization period until discharge or a maximum of 7 days after ICH onset .

Data Collection

Clinical data were extracted from EHR system, including admission notes, daily progress notes, laboratory results, intensive care unit (ICU) records, and discharge diagnoses. Neuroimaging data, mainly computed tomography (CT) scans, were also collected for diagnostic confirmation and clinical characterization. All data were de-identified before analysis.

To address potential bias and ensure the robustness of the study results, we utilized a consecutive enrollment strategy, including all primary ICH patients who met the inclusion criteria between 2021 and 2024, thereby minimizing the risk of selective participant inclusion. Additionally, the diagnosis of ICH-SAP was independently verified by two trained researchers to ensure outcome accuracy.

Inclusion Criteria

Patients were included if they:

1. Diagnosed with primary ICH;
2. Aged ≥ 18 years at the time of admission;
3. Lung CT imaging available;
4. The first admission for the ICH episode occurred at West China Hospital. (Figure 2)

Diagnostic Criteria for SAP Patients

For the purpose of this study, ICH-SAP was strictly defined as a lower respiratory tract infection (LRTI) occurring within 7 days after the onset of ICH.

The ICH-SAP was diagnosed using criteria derived from the Centers for Disease Control and Prevention (CDC) for SAP, which requires evidence from three aspects: laboratory results (such as white blood cell count), clinical signs and symptoms (such as fever, cough), and imaging confirmation (specifically, CT to confirm the presence of pulmonary infection)¹³.

Pneumonia is diagnosed when patients have fever ($>38^{\circ}\text{C}$) without another cause, leukopenia ($<4,000/\text{mm}^3$) or leukocytosis ($>12,000/\text{mm}^3$), or if ≥ 70 years with altered mental status. Together with at least two clinical findings, including sputum, secretions, or cough, dyspnea, tachypnea ($>25/\text{min}$), rales/crackles/bronchial breath sounds, or worsening gas exchange. Diagnosis additionally required chest radiographs showing new or progressive infiltrates, consolidation, or cavitation¹⁴.

To ensure the credibility of the diagnosis, the adjudication of SAP was conducted by two independent researchers based on the procedure described above. The researchers reviewed the EHR, including clinical symptoms, laboratory findings, and chest CT images blinded to each other's findings. Inter-rater agreement for SAP diagnosis was assessed on a random subset of 100 cases (approximately 5.2% of the full sample of 1,931 patients). The observed percentage agreement was 95.0% (95/100), with a Cohen's kappa of 0.88 (95% CI: 0.83–0.93), indicating almost perfect agreement. Discrepancies in diagnosis were resolved through mutual consensus; if the disagreement persisted, a third senior investigator performed a final review to reach a definitive adjudication.

Differential Diagnosis(DDx)

To ensure the cohort was restricted to true ICH-SAP, two primary confounding types of pneumonia were excluded:

1. Community-Acquired Pneumonia (CAP): Patients diagnosed with CAP were not counted as SAP, since their infection are earlier than ICH onset..¹⁵
2. Ventilator-Associated Pneumonia (VAP): VAP, defined as a lung infection caused by mechanical ventilation, was not diagnosed as SAP. Specifically, any lower respiratory tract infection occurring 48 hours or more after the time of intubation was categorized as VAP not SAP¹⁶but in still in the ICH population.

Statistical Analysis

The primary outcome of this study was the 7 days or in-hospital cumulative risk of ICH-SAP, which was strictly defined as the above criteria. Due to observational study, some patients were discharged early (e.g., after only 2–3 days), transferred, or died before completing the full 7-day observation window. Therefore, the primary outcome was defined as the 7-day in-hospital risk (i.e., risk during hospitalization within 7 days or before discharge).

Data analysis was performed using SPSS software. Descriptive statistics were used to summarize the baseline characteristics and clinical data of the study population ($n=1,931$). Quantitative variables (Continuous variables), including age, body mass index (BMI), systolic blood pressure (SBP), diastolic blood pressure (DBP), and admission temperature, were presented as mean $\pm$ standard deviation (SD). Categorical variables, such as sex, side of haematoma (Left, Right, Both, or Not identified), location of

the haematoma (Cortical, Cerebellum, Deep, or Brainstem), and the presence of intraventricular haemorrhage (IVH), were expressed as frequencies and percentages.

Regarding missing data, the clinical information extracted from the EHR system was comprehensive for the 1,931 included patients.

The study focused on the risk of SAP during the acute phase, participants were followed from ICH onset through a maximum of 7 days or before discharge

Ethical approval Standard Protocol Approvals, Registrations, and Patient Consents

This retrospective study was approved by the Biomedical Ethics Committee of West China Hospital, Sichuan University (Approval No. 2023-2308). All procedures were performed in accordance with the ethical standards of the Declaration of Helsinki. Given the retrospective design and the use of de-identified clinical data from the electronic health record system, the requirement for written informed consent was waived by the ethics committee.

Meta-Analysis

This systematic review and meta-analysis was performed according to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) guidelines¹⁷. Data not published within the article are available from the corresponding author upon reasonable request.

Search Strategy

The search query was designed to capture all citations reported from inception to October, 2025. To identify studies developing or validating prediction models for SAP following ICH. To identify eligible studies within PubMed, the following keywords were used in combination with the Boolean operators OR and AND: intracerebral hemorrhage, stroke-associated pneumonia, prediction model. The full search queries are listed in the Supplemental Material.

Study Selection

Studies were included if they enrolled both male and female adult patients, reported prediction models for SAP following ICH including demographic characteristics and were written in English language. After duplicate removal, 2 independent reviewers (Xiuye Guo. and Xing Wang) screened the studies by title and abstract. Conflicts were resolved by consensus between the 2 reviewers. Disagreements between reviewers were resolved through discussion or by consultation with a third investigator. We further excluded studies focusing on stroke subtypes other than primary ICH, such as ischemic stroke or subarachnoid hemorrhage(SAH), intraventricular hemorrhage(IVH). Lastly, letters, conference abstracts,

and reviews without original data were excluded Furthermore, Studies lacking detailed numbers of ICH cases and SAP events were excluded. Lastly, letters, conference abstracts, and reviews without original data were excluded.

Eligible studies were required to meet the following criteria(Figure 1)

1. Studies had to develop or validate at least one prediction model for estimating the risk or incidence of SAP following ICH.
2. SAP diagnosis based on the Centers for Disease Control and Prevention (CDC) criteria, defined as a lower respiratory tract infection occurring within 7 days after ICH onset as described above. If a patient was discharged. or transferred before day 7 , no further diagnosis for SAP was performed. Patients who died before 7days were also excluded from further observation (i.e., follow-up was censored at death).
3. Primary ICH population confirmed by clinical and imaging findings, with excluding studies focusing on stroke subtypes other than primary ICH, such as ischemic stroke or subarachnoid hemorrhage(SAH), intraventricular hemorrhage (IVH)
4. Available on data, such as the number of SAP events and the total number of ICH patients.
5. Letters, conference abstracts, and reviews without original data were excluded

Assessment of Risk of Bias

Although the Prediction model Risk Of Bias Assessment Tool (PROBAST) ¹⁸ is recommended for prediction model studies, a PROBAST-based assessment was not performed in this review because the primary objective was not to evaluate prediction model performance, but to examine temporal trends in the risk of SAP following ICH. Therefore, we assessed the quality of the included studies using an adapted version of the Newcastle–Ottawa Scale (NOS)¹⁹ for cohort studies(Supplementary Material). The scale evaluates three domains: (1) selection, (2) information. For the purpose of this review, the NOS was tailored to emphasize aspects relevant to SAP risk after ICH, including clarity of ICH diagnosis, consistency of SAP definition and diagnosis (CDC criteria within ≤ 7 days), precision of selection of ICH patients. Each study was categorized as having low, possible, or high risk of bias within each domain(Supplementary Table S2). Studies with a high risk of bias in ≥ 2 domains were considered methodologically weak and were excluded from quantitative synthesis.

Data Extraction

We extracted data including study period , number of total people and SAP people, SAP proportion, number of male and female, median age.

Statistical Analysis

All statistical analyses were conducted using R software (version 4.1.3) with the package “meta”. The primary outcome proportion. These data were collected from the included studies. Because the inclusion, exclusion criteria and the diagnostic strategy in each study included is the same as the West China Hospital cohort described above, the proportion for each study can likewise be interpreted as the 7-day or in-hospital risk.

The pooled proportion of SAP after ICH was estimated using a random-effects model (DerSimonian–Laird method). Proportions were logit-transformed to stabilize variance, and 95% confidence intervals (CIs) were computed for both individual studies and pooled estimates.

Between-study heterogeneity was assessed using Cochran’s Q test and quantified with the I^2 statistic. When substantial heterogeneity was detected ($I^2 > 50\%$), potential sources were further explored through subgroup and meta-regression analyses.

A subgroup analysis was conducted according to the study period (before 2019, across 2019 and after 2019) to examine potential temporal changes in SAP risk. The year 2019 was used as the cutoff for subgroup analyses because the data about incidence were published on 2019 or earlier. This cutoff enabled a comparison between periods before and after 2019. Studies with data across 2019 could not be assigned to either the pre-2019 or post-2019 group; they were therefore classified as a separate “across 2019” subgroup, especially considering that the COVID-19 pandemic occurred within their study periods. Sensitivity analyses were performed using the leave-one-out method, in which each study was sequentially excluded to evaluate the stability of pooled estimates and identify influential studies.

To assess the association between SAP risk and publication year, a mixed-effects meta-regression model was applied, with the median study year as a continuous covariate. This approach allowed estimation of time-dependent trends in SAP risk across studies.

Publication bias was evaluated visually using funnel plots and statistically using Egger’s regression test for funnel plot asymmetry. A two-tailed p value < 0.05 was considered statistically significant for all analyses.

Ethical approval ***Standard Protocol Approvals, Registrations, and Patient Consents***

The meta-analysis was conducted using data extracted from published studies, which did not involve individual patient identifiers, therefore, ethical approval and informed consent were not required.

Artificial Intelligence Statement

ChatGPT (OpenAI) was used only for language polishing and grammar refinement during manuscript preparation. All AI-assisted outputs were reviewed and verified by the authors.

Results

Characteristics of ICH Patients and ICH-SAP patients of West China Hospital Cohort

The final study cohort comprised a total of 1,931 patients diagnosed with ICH. The mean age of the patients was 57.02 years, with a male proportion of 65% (1,266/1,931) of the cohort. The average Body Mass Index (BMI) was recorded as 24.43. Upon admission, mean vital parameters were documented as a mean Systolic Blood Pressure (SBP) of 151.75 mmHg and a Diastolic Blood Pressure (DBP) of 89.99 mmHg, with a mean body temperature of 36.73°C (Table 1). The majority of bleeding occurred in the deep brain structures (1,074/1,931, 55.62%), followed by cortex (652/1,931, 33.76%), brainstem (176/1,931, 9.11%) and the cerebellum (131/1,931, 6.78%). Associated intraventricular hemorrhage (IVH) was observed in 493 patients (25.3%) (Table 1).

Among them, 936 patients (48%) developed SAP during hospitalization (Table 1). Patients who were diagnosed with pneumonia at the time of admission were diagnosed as CAP (599/1,931, 31.0%). Ventilator-associated pneumonia (VAP) was identified in 73 patients (3.7%). Baseline characteristics were summarized and compared between SAP and Non-SAP groups in Table 1.

Meta-analysis

We identified 123 records through PubMed database searching. Following screening and eligibility assessment, 18 studies met the predefined inclusion criteria and were included in the final meta-analysis. Studies were excluded if they did not develop or validate a prediction model for SAP after ICH, applied diagnostic criteria inconsistent with the CDC definition (≤ 7 days after ICH), included non-primary ICH populations (e.g., ischemic stroke, subarachnoid hemorrhage, or intraventricular hemorrhage), provided insufficient data on SAP events or total ICH cases, or were publication types lacking original data (e.g., letters, conference abstracts, or reviews) (Figure 1).

Detailed information on the characteristics of the included studies is presented in Supplementary Table S1. Quality assessment of the included studies is summarized in Table S2. None of the studies demonstrated a high risk of bias in ≥ 2 domains, and therefore all eligible studies were retained for the meta-analysis.

Subgroup Analysis

In the subgroup analysis stratified by study period, a marked difference in SAP pooled proportion was observed between cohorts. (Figure 3) Studies conducted before 2019 ($n = 115,536$) yielded a pooled SAP proportion of 22% (95% CI: 19–25%), studies across 2019 ($n = 1,071$) had a pooled SAP proportion of 48% (95% CI: 35–62%), and studies conducted after 2019 ($n = 1,796$) reported a substantially higher pooled proportion of 39% (95% CI: 24–57%). The test for subgroup differences was statistically

significant ($\chi^2 = 19.48$, $df = 2$, $p \leq 0.0001$), indicating possible a temporal increase in the occurrence of SAP.(Figure 3)

However, heterogeneity was high in both subgroups ($I^2 > 97\%$), indicating that these pooled estimates should be interpreted cautiously and not be viewed as precise summary estimates applicable across all clinical settings.

The corresponding 95% prediction intervals were 0.13–0.34 for studies before or up to 2019, 0.05–0.89 for studies after 2019, and 0.07–0.92 for studies spanning 2019, indicating substantial between-study variability.

Sensitivity Analysis of Studies Conducted Before 2019

Sensitivity analysis was conducted for the subgroup of studies **before 2019** using the **leave-one-out method** (Supplementary Figure 4). After sequentially omitting each study, the pooled SAP proportion remained stable, ranging from **21% to 23%**, with no single study exerting a disproportionate influence on the overall estimate. The **95% confidence intervals** for each study overlapped substantially, further supporting the robustness of the findings. The I^2 statistic was high (**98.3%**), indicating significant heterogeneity, but the results remained consistent despite the variability between studies.(Supplementary Figure 4)

These findings suggest that the SAP proportion estimate for studies conducted before 2019 is robust and not influenced by any one study. The overall pooled SAP proportion for studies before 2019 was **22% (95% CI: 19–25%)**.

Sensitivity Analysis of Studies Conducted After 2019

Sensitivity analysis was also conducted for the subgroup of studies after 2019 (Figure 5). The results support the conclusion that risk of ICH-SAP after 2019 may be higher than the historical proportion of approximately 22%(Figure 5).

The overall pooled estimate was 0.38, with a 95% confidence interval of [0.35, 0.40], indicating an temporal change in SAP risk after 2019(Figure 5).

Sensitivity Analysis of Studies Conducted Across 2019

Sensitivity analysis was also conducted for the subgroup of studies across 2019 (Figure 6). The results support the conclusion that SAP risk across 2019 has also increased compared to the historical rate of approximately 22%(Figure 6).

The overall pooled proportion was 0.45(95% CI, 0.42-0.48), indicating a possible temporal change in SAP risk across 2019.

Meta regression of SAP over time

Meta-regression was performed using the study median year as a continuous covariate to explore the association between calendar time and logit-transformed SAP proportion. In the mixed-effects model with REML estimation, study mid-year was positively associated with SAP proportion (coefficient = 0.0684, SE = 0.0288, $z = 2.3750$, $p = 0.0175$; 95% CI: 0.0120–0.1248). The model accounted for 29.5% of the between-study heterogeneity, although substantial residual heterogeneity remained ($\tau^2 = 0.3375$; $I^2 = 64.37\%$; $QE = 46.2637$, $p < 0.001$). Therefore, the meta-regression suggested a positive temporal association, but the result should be interpreted cautiously given the limited number of studies, residual heterogeneity, and the influence of individual studies. (Figure 7).

In a sensitivity analysis excluding Zhao 2023, the study with the highest SAP proportion (163/200, 81.5%), the positive association remained statistically significant ($\beta = 0.0511$, SE = 0.0206, $z = 2.48$, $p = 0.0131$; 95% CI: 0.0107–0.0915).

Publication Bias Analysis

Visual inspection of the funnel plot (Figure 8) revealed some degree of asymmetry; however, this observation should be interpreted with caution due to substantial between-study heterogeneity. Egger's regression test did not confirm statistical significance ($t = 0.87$, $df = 16$, $p = 0.3977$), although the positive bias estimate carried considerable uncertainty (estimate = 1.9465, SE = 2.2401). Study-level model weights in the mixed-effects meta-regression were relatively balanced, ranging from 5.31% to 5.69%. This suggests that the temporal association was not driven by a single dominant study. Detailed study-level data, including study period, SAP events, total sample size, SAP proportion, and model weight, are presented in Supplementary Table .

Discussion

SAP remains one of the most clinically relevant complications after intracerebral hemorrhage (ICH), but its contemporary burden remains insufficiently defined. Earlier guidelines and epidemiological studies generally reported SAP rates of approximately 15–30%. However, many of these estimates were derived from studies conducted before 2019 and may not fully reflect recent changes in patient characteristics, diagnostic practices, imaging availability, and healthcare-system factors. In addition, previous studies have differed substantially in SAP definitions, follow-up windows, clinical settings, and case ascertainment strategies. These uncertainties make it difficult to determine whether SAP after ICH has become more common in contemporary practice or whether higher reported rates are mainly attributable to methodological differences and increased diagnostic intensity.

In the present study, we examined the early in-hospital burden of SAP among patients with ICH treated at West China Hospital between 2021 and 2024 and further synthesized published evidence through a meta-analysis. In our single-center cohort, the 7-day or in-hospital cumulative risk of SAP was 48.5%, which was higher than rates commonly reported in earlier literature. Because some patients may have been discharged, transferred, or censored before completing a uniform early SAP risk window, this estimate should be interpreted as an early in-hospital cumulative risk rather than a true incidence rate based on person-time observation. Nevertheless, the finding indicates that SAP remains a substantial complication after ICH in contemporary clinical practice.

A key question is whether the high SAP risk observed in our cohort reflects a broader epidemiological pattern or center-specific factors. We acknowledge that the absence of pre-2019 internal data limits our ability to directly quantify temporal changes within West China Hospital. Therefore, the high cumulative risk observed in this cohort may partly reflect local practice patterns, patient selection, diagnostic thresholds, imaging availability, or institutional workflow. However, several baseline findings provide some reassurance that the observed SAP burden was not simply driven by an obviously more severe SAP group. The SAP and non-SAP groups were broadly comparable across several baseline characteristics. Moreover, the proportion of brainstem hemorrhage was not higher in the SAP group and was numerically higher in the non-SAP group, suggesting that the excess SAP risk was unlikely to be explained solely by overrepresentation of patients with clinically severe hemorrhage locations. Similarly, intraventricular hemorrhage, an important marker associated with poor outcomes after ICH, did not differ significantly between the SAP and non-SAP groups. Although these observations cannot exclude residual confounding, they suggest that the high SAP burden cannot be fully attributed to obvious imbalances in selected severity-related baseline features.

The requirement for lung CT imaging should also be interpreted in context. Lung CT availability was included to improve diagnostic reliability, but in actual patient selection, no patient was excluded solely because lung CT was unavailable. At West China Hospital, patients with ICH are prioritized for early imaging and routinely undergo lung CT at admission or when pneumonia is clinically suspected. This reduces the likelihood that the CT criterion substantially narrowed the cohort. Nevertheless, this imaging-based diagnostic approach may still reflect local practice patterns and may limit generalizability to centers with different imaging workflows.

To explore whether the high cumulative risk observed in our cohort was consistent with broader evidence, we performed a meta-analysis of published studies reporting SAP after ICH. The subgroup analysis suggested that studies conducted after 2019 had a higher pooled SAP proportion than earlier studies. Meta-regression using study mid-year as a continuous covariate also suggested a positive temporal association, and this association remained statistically significant after excluding the visually apparent high-incidence study. In addition, the relatively similar model weights across studies suggest that no single study overwhelmingly dominated the meta-regression result. This pattern is expected in a mixed-effects framework when between-study heterogeneity is substantial, because between-study variance contributes importantly to the weighting structure.

However, these meta-analytic findings should be interpreted cautiously. Heterogeneity was extremely high across subgroups, and the 95% prediction intervals were wide, particularly in the post-2019 subgroup. The small number of studies, residual heterogeneity, and variability in diagnostic criteria, study populations, and clinical practice patterns may affect the stability and interpretability of the temporal association. Therefore, the meta-regression should be viewed as supportive exploratory evidence rather than definitive proof of a secular increase in SAP risk.

Several factors may explain the substantial heterogeneity observed in the meta-analysis. The included studies differed markedly in sample size, ranging from several hundred to tens of thousands of patients, which may have influenced the precision, stability, and weighting of pooled estimates. They also varied in geographic region, clinical setting, patient age, baseline stroke severity, SAP diagnostic criteria, availability and timing of chest imaging, follow-up window, and study design. Institutional differences in dysphagia screening, airway management, antibiotic use, intensive care admission, and infection-control practices may also have contributed to the observed variation in SAP proportions. These clinical and methodological differences reduce the interpretability and generalizability of a single pooled estimate.

The findings of the meta-analysis should also be considered in light of several methodological limitations. First, our search strategy focused on studies reporting SAP incidence or developing prediction models for SAP after ICH. This targeted strategy improved relevance to the present research question, but it may have been relatively narrow and may not have captured all observational cohorts reporting SAP as a secondary outcome. As a result, the evidence base may have been enriched for studies specifically concerned with SAP prediction or risk modeling, which could have contributed to heterogeneity and limited representativeness. Second, publication bias assessment requires caution. Egger's test did not show statistically significant evidence of funnel plot asymmetry, but visual inspection suggested some degree of asymmetry. In prevalence-type meta-analyses with a limited number of studies and substantial heterogeneity, funnel plot asymmetry may arise from small-study effects, differences in population characteristics, diagnostic thresholds, sample size, study design, or clinical setting rather than publication bias. Therefore, although no robust statistical evidence of publication bias was detected, small-study effects or heterogeneity-related asymmetry could not be excluded. Third, although most included studies were rated as having low or possible risk of bias using the adapted Newcastle–Ottawa Scale, this assessment primarily reflects selected methodological features of individual observational studies and should not be interpreted as high certainty of evidence for a temporal increase in SAP burden. Given the extreme heterogeneity, wide prediction intervals, limited number of studies, and absence of a formal certainty-of-evidence assessment such as GRADE, the overall strength of evidence remains limited.

Several limitations of the single-center cohort should also be acknowledged. Due to the retrospective observational design, complete data on in-hospital mortality and cause of death, including whether death was primarily neurological or non-neurological, were not available for all patients, particularly those discharged early or lost to follow-up. This limitation precludes a full assessment of mortality burden in the SAP and non-SAP subgroups. In addition, because the cohort lacked pre-2019 internal data, it cannot

directly establish whether SAP risk increased over time within our institution. Therefore, the cohort should be interpreted as providing detailed contemporary single-center evidence rather than direct evidence of a within-center temporal trend.

Taken together, these limitations affect the interpretation of both the cohort and the meta-analysis. The single-center cohort provides detailed contemporary data from a large tertiary center but lacks an internal historical comparison. The meta-analysis provides broader context but is affected by heterogeneity, possible small-study effects, variability in diagnostic and follow-up methods, and limited certainty of evidence. Consequently, the present study cannot establish a definitive temporal trend or causal explanation for changes in SAP burden after ICH. Instead, the combined evidence supports a more cautious interpretation: SAP may represent a larger or more clinically apparent burden in some contemporary ICH settings, but this hypothesis requires further validation.

From a clinical perspective, the findings emphasize the need for continued attention to SAP prevention and early detection after ICH. Current prevention strategies mainly focus on dysphagia screening, aspiration prevention, early mobilization, and general infection-control measures. If SAP burden is indeed higher in some modern clinical settings, more refined risk stratification and targeted prevention strategies may be needed. However, given the current uncertainty, changes to guidelines or routine practice should be based on additional multicenter evidence rather than on pooled estimates alone.

Future research should clarify the contemporary epidemiology, determinants, and prognostic impact of SAP after ICH. Large-scale, multicenter prospective cohorts with harmonized SAP diagnostic criteria and standardized follow-up windows are needed to more precisely estimate cumulative risk and incidence rates. Such studies should distinguish early in-hospital SAP from later pneumonia and account for competing events such as early death, transfer, or discharge. Future studies should also evaluate causal associations between SAP and clinical outcomes, examine whether SAP has different prognostic effects across ICH subtypes or hemorrhage locations, and determine whether targeted prevention strategies can reduce SAP burden and improve functional recovery.

In conclusion, SAP remains a substantial complication among patients with ICH in contemporary practice. The high cumulative risk observed in our cohort and the higher pooled proportion in recent studies raise an important hypothesis that SAP burden may have increased or become more clinically apparent in recent years. However, given the lack of within-center historical data, extreme heterogeneity, wide prediction intervals, and limitations of the available evidence base, this interpretation should remain cautious. Rather than establishing a definitive temporal increase, the present study provides evidence that warrants further prospective, multicenter investigation.

Conclusion

In this single-center retrospective cohort study combined with a systematic review and meta-analysis, we observed a higher cumulative risk of SAP after ICH than that reported in earlier literature and contemporary guidelines. Meta-analytic evidence further suggested a possible temporal increase in

reported SAP risk among studies spanning across or conducted after 2019. Collectively, these findings suggest that the burden of SAP after ICH may have been underestimated in recent years and support the hypothesis that SAP may have become more frequent or more clinically apparent in some contemporary settings. However, given the substantial heterogeneity and limitations of the available evidence, this hypothesis requires further validation in large-scale prospective multicenter studies.

Declarations

Compliance with ethical standards

The authors confirm that the manuscript complies with all instructions to authors of Neurocritical Care.

Authorship and approval of the manuscript

All authors meet the authorship criteria. All authors have made substantial contributions to the study and have approved the final version of the manuscript.

Originality and prior publication

This manuscript has not been published previously and is not under consideration for publication in any other journal.

Use of reporting checklists

The authors confirm that the appropriate reporting checklists (PRISMA for the meta-analysis and STROBE for the cohort study) have been completed and submitted .

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Conflict of interest

The authors declare no conflicts of interest.

Ethics approval

Approved by the Ethics Committee of West China Hospital, Sichuan University. The requirement for informed consent was waived due to the retrospective nature of this study.

Consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data and materials

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Code availability

Not applicable.

Authors' contributions

All authors contributed to the conception and design of the study. All authors reviewed and approved the final manuscript.

Acknowledged

NA.

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Tables

Table 1 and 2 are available in the Supplementary Files section.

Figures

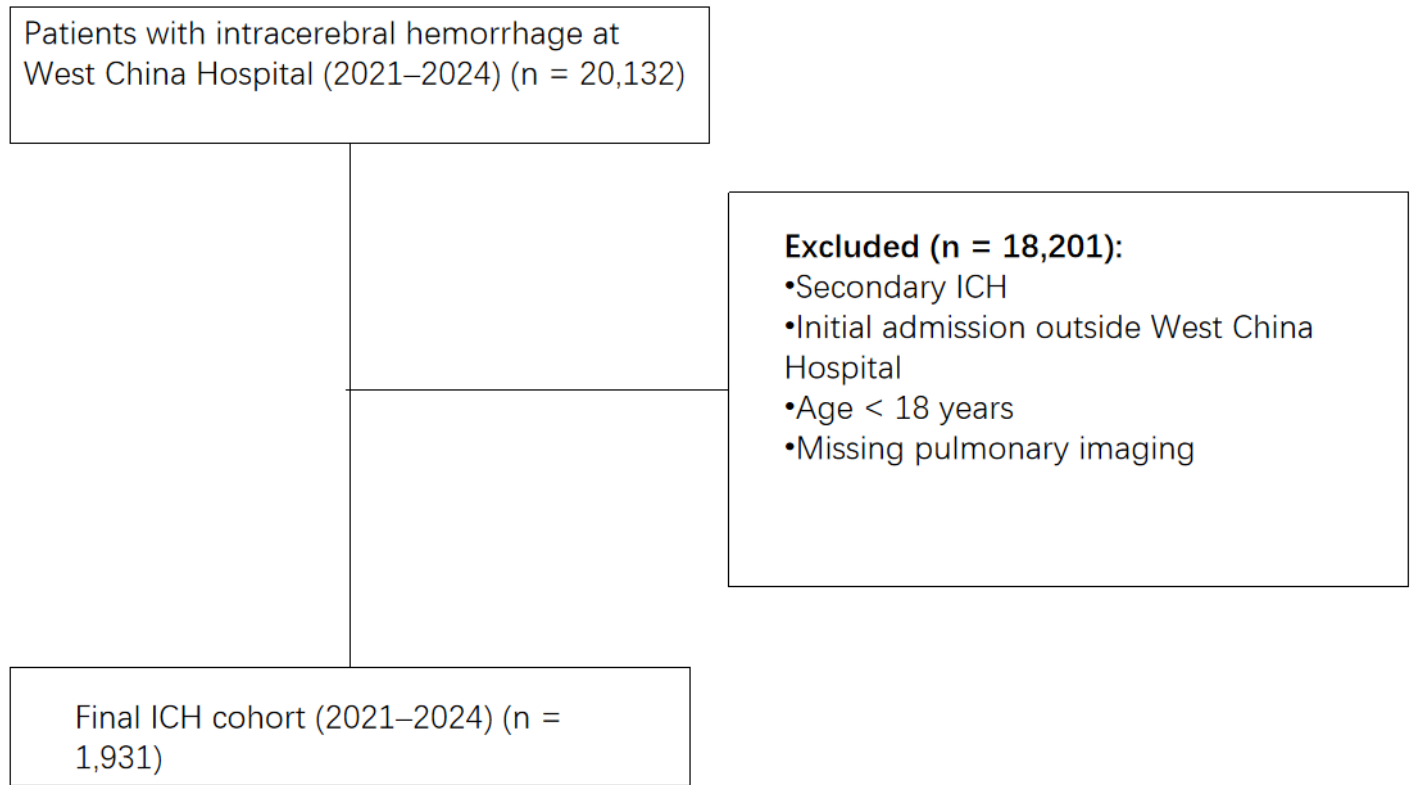


Figure 2

Flow diagram of patient selection in the single-center cohort.

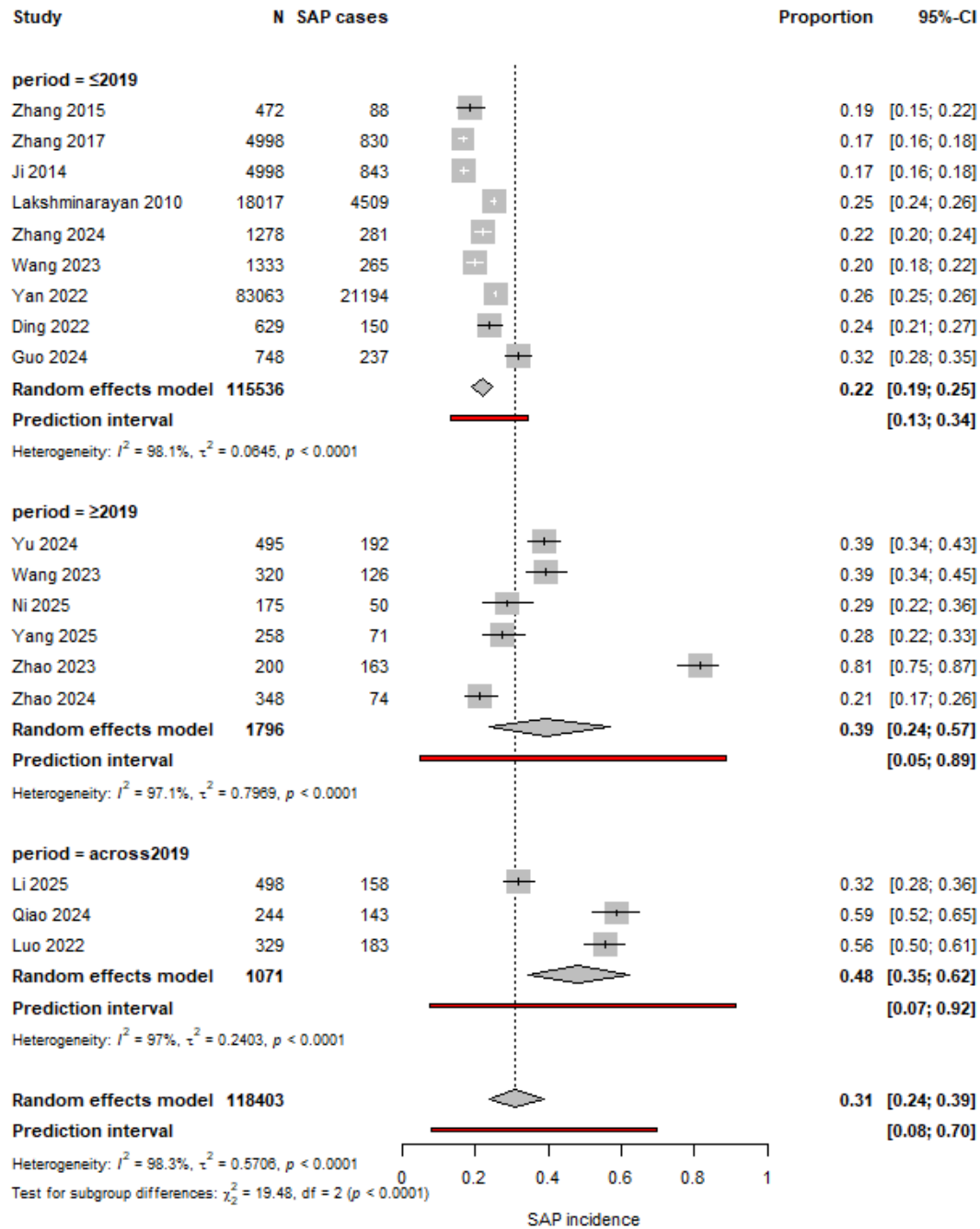


Figure 3

Forest plot of pooled proportion of SAP in patients with ICH.

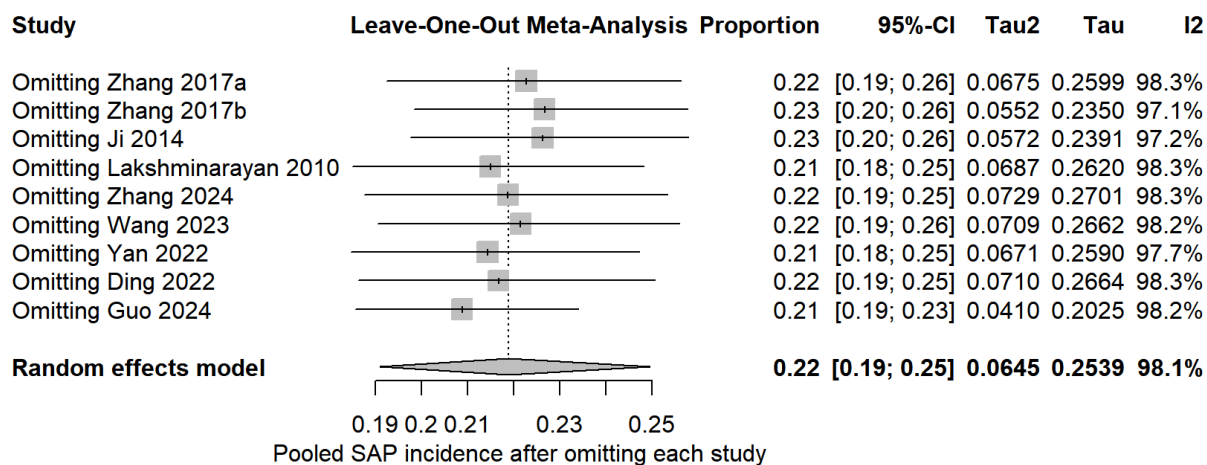


Figure 4

Sensitivity analysis of pooled SAP proportion for studies conducted before 2019, using the leave-one-out method.

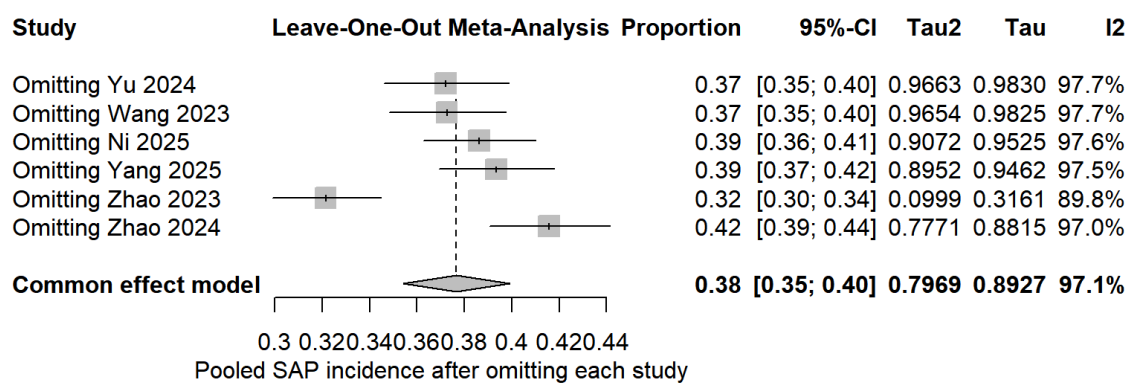


Figure 5

Sensitivity analysis of pooled SAP proportion for studies conducted after 2019, using the leave-one-out method.

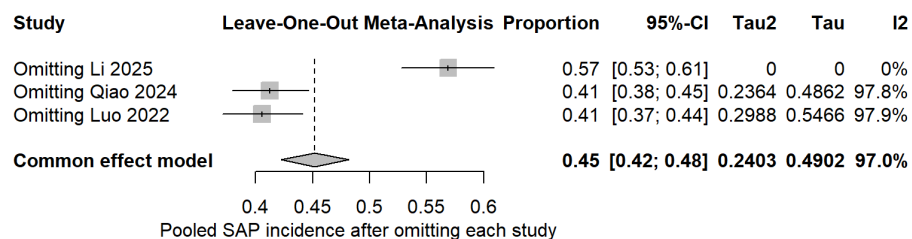


Figure 6

Sensitivity analysis of pooled SAP proportion for studies conducted across 2019, using the leave-one-out method.

Meta Regression of SAP Incidence Over Time

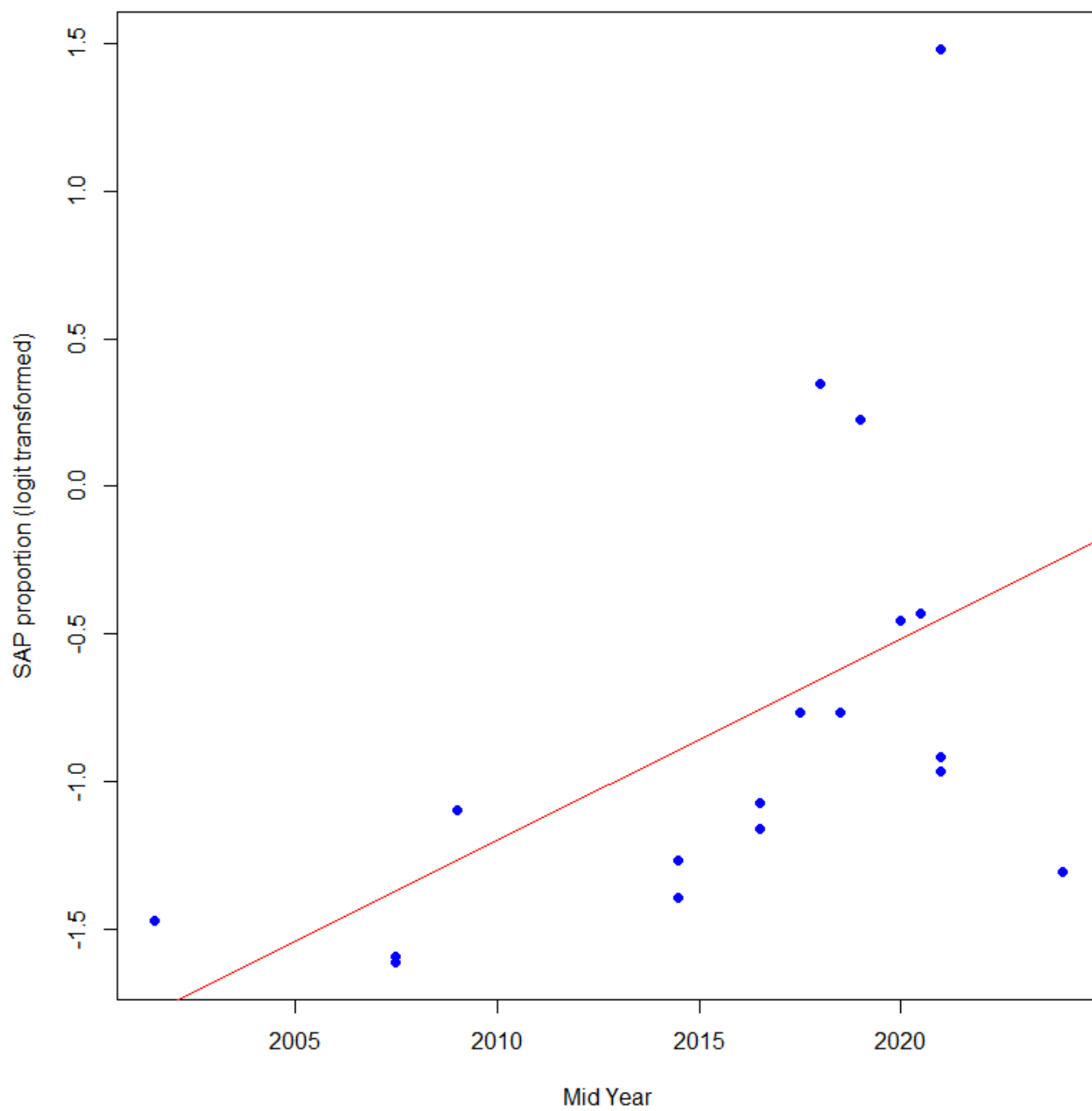


Figure 7

Meta-regression of SAP proportion and study median year.

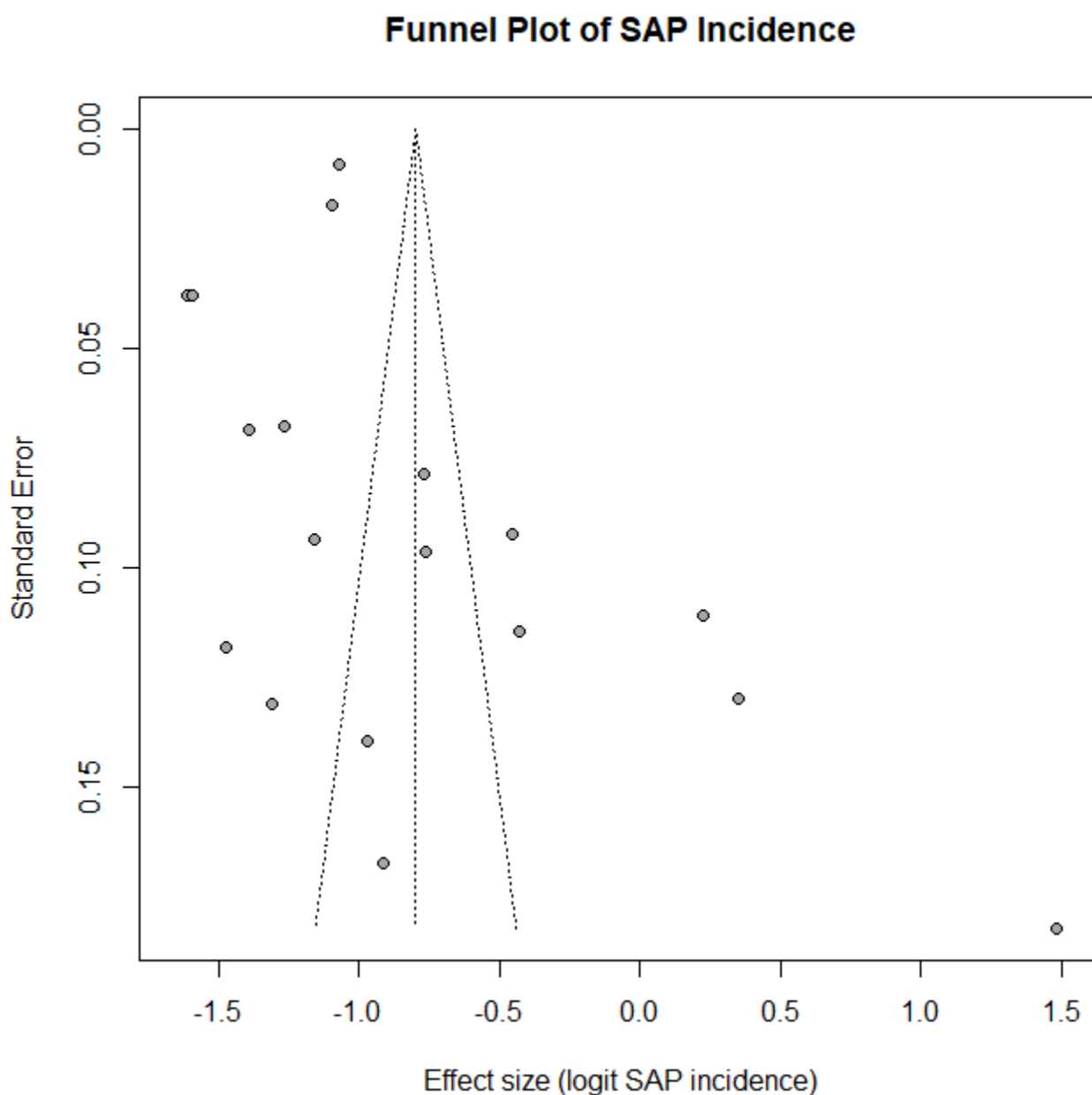


Figure 8

Funnel plot of the pooled proportion of SAP after ICH.

Supplementary Files

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